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14. ABSTRACT

The investigators have undertaken several efforts underlying the enhancement of the performance of nanostructure-based quantum-dot-based optoelectronic devices. These include: the use of colloidal quantum dots as optoelectronic elements; investigating novel nanostructures (including graphene and CNTs as contacts) as components of quantum-dot based optoelectronic devices; investigating confined phonon effects in novel components of the integrated nanostructure-based optoelectronic structures; investigating energy transfer between quantum dot and PS-I; and the investigation of photodetector structures from these nanostructures and conducting polymers. Specific achievements include: first measurement of FRET times between PS-I and semiconductor quantum dots; measurement of large NDR in organic-inorganic optoelectronic structures; measurement of confined phonons in quantum dots; and design of novel three-color organic-inorganic photodetectors.

15. SUBJECT TERMS
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ANNUAL TECHNICAL (MAR08-AUG11) REPORT ON

AFOSR FA9550-08-1-0152

"(NANOTECHNOLOGY INITIATIVE) REVISION OF QUANTUM ENGINEERING OF NANOSTRUCTURES FOR OPTOELECTRONIC DEVICES WITH OPTIMUM PERFORMANCE"

(1) Introduction

The investigators have undertaken several efforts underlying the enhancement of the performance of nanostructure-based quantum-dot-based optoelectronic devices. These include: the use of colloidal quantum dots as optoelectronic elements; investigating novel nanostructures (including graphene and CNTs as contacts) as components of quantum-dot based optoelectronic devices; investigating confined phonon effects in novel components of the integrated nanostructure-based optoelectronic structures; investigating energy transfer between quantum dot and PS-I; and the investigation of photodetector structures from these nanostructures and conducting polymers. Specific achievements include: first measurement of FRET times between PS-I and semiconductor quantum dots; measurement of large NDR in organic-inorganic optoelectronic structures; measurement of confined phonons in quantum dots; and design of novel three-color organic-inorganic photodetectors.

(2) List of Appendixes --- N/A

(3) Statement of Problem Studied

The problem addressed in this AFOSR effort on high-performance quantum-dot-based devices is to design and characterize nanostructures whose electronic and optical properties are tailored using quantum-engineering techniques. The investigators study mechanisms, phenomena, and interactions --- confinement-induced shifts in the phonon frequencies, energy exchange between quantum dots and PS-I; carrier transport in nanostructures and nanostructure—conductive-polymer systems, band formation quantum dots embedded in conducting polymers, quantum-dot interactions with graphene-based nanostructures --- having potential for enhancing the performance of quantum-dot-based optoelectronic devices.

(4) Summary of Most Important Results

The most important results obtained during this period of this effort include: electrical and optical studies of components of devices and systems of quantum-dot-based optoelectronic devices; electronic and optical properties of quantum dots in ensembles; characterization of quantum-dot blinking phenomena; characterization of phonon modes in quantum dots; and extending a theory band formation in an array of colloidal quantum dots embedded in conductive polymer. Specific results were obtained on the following topics:

Confinement in PbSe Wires grown by RF Magnetron Sputtering

Negative Differerential Resistance in Conductive Polymer and Semiconducting Quantum Dot Nanocomposite Systems

Transmission Coefficients for Minibands Formed in Quantum Dot Arrays under Bias

Miniband Formation in Superlattices of Colloidal Quantum Dots and Conductive Polymers

Phonon Modes in Self-assembled GaN Quantum Dots

Quantum Dot Blinking: Physical Limit for Nanoscale Optoelectronic Device

Three-color Photodetector based on Quantum Dots and Resonant-tunneling Diodes coupled with Conductive Polymers

Optical and Electrical Measurement of Energy Transfer between Nanocrystalline Quantum Dots and Photosystem

Phonon Bottleneck Effects in Rectangular Graphene Quantum Dots

Interface Optical Phonon Modes in Wurtzite Quantum Heterostructures

Multi-Color Photodetector based on Quantum Dots and Resonant-Tunneling Diodes Coupled with Conductive Polymers

Growth and Properties of Tin Oxide Nanowires and the Effect of Annealing Conditions

Phonon Modes in Semiconductor Quantum Dots

Optical Phonon Modes in Rectangular Graphene Quantum Dots

Evidence of Compositional Inhomogenity in $In_xGa_{1-x}N$ alloys using Ultraviolet and Visible Raman Spectroscopy

Rapid Thermal Annealing Effects on Tin Oxide Nanowires Prepared by Vapor-liquid-solid Technique

Observation of UV Emission, and Effect of Surface States on the Luminescence from Tin Oxide Nanowires

Direct Measurement of Electical Transport through Single Molecules

Colloidal Quantum Dots (QDs) in Optoelectronic Devices --- Solar Cells, Photodetectors, Light-emitting Diodes

Applications of Colloidal Quantum Dots

Graphite C-axis Thermal Conductivity

Thermal Conductivity of Carbon Nanotubes

(5) List of Publications and Technical Reports

PAPERS PUBLISHED

Hyeson Jung, Rade Kuljic, Mitra Dutta, and Michael A. Stroscio, "Confinement in PbSe Wires grown by RF Magnetron Sputtering," Applied Physics Letters, 96, 153106 (2010); published online, April 15, 2010.

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Takayuki Yamanaka, Dimitri Alexson, Michael A. Stroscio, and Mitra Dutta, Pierre Petroff, Jay Brown, and James Speck, "Phonon modes in self-assembled GaN quantum dots," Journal of Applied Physics, 104, 093512 (2008).

Sicheng Liao, Mitra Dutta, Dan Schonfeld, Takayuki Yamanaka, and Michael A. Stroscio, "Quantum Dot Blinking: Physical Limit for Nanoscale Optoelectronic Device," Journal of Computational Electronics, 7, 462-465 (2008).

Sicheng Liao, Ke Sun, M. Dutta and M. A. Stroscio, Three-color Photodetector based on Quantum Dots and Resonant-tunneling Diodes coupled with Conductive Polymers, Solid State Electronics, 54, 1066-1070 (2010).

Hyeson Jung, Galina Gulis, Subhadra Gupta, Kevin Redding, David J. Gosztola, Gary P. Wiederrecht, Michael A. Stroscio, and Mitra Dutta, Optical and Electrical Measurement of Energy Transfer between Nanocrystalline Quantum Dots and Photosystem I, J. Phys. Chem. B, 114, 14544-14549 (2010).

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S. Liao, M. Dutta, and M. Stroscio, Multi-Color Photodetector based on Quantum Dots and Resonant-Tunneling Diodes Coupled with Conductive Polymers International Workshop on Computational Electronics (IWEC), Pisa, Italy, October 26-29 2010, Pisa University Press, pp. 267-270, IEEE Catalog Number CFP10462-PRT, ISBN: 978-1-4244-9381-4 (2010).

Ayan Kar, Michael A. Stroscio, Mitra Dutta, Jyoti Kumari, and M. Meyyappan, “Growth and Properties of Tin Oxide Nanowires and the Effect of Annealing Conditions,” Semiconductor Science and Technology, 25, 024012-1-9 (2010).

Sushmita Biswas, Mitra Dutta, Preston Snee, and Michael A. Stroscio, Phonon Modes in Semiconductor Quantum Dots, Chinese Journal of Physics, 49 (1), 92-99 (2011).

Jun Qian, Mitra Dutta, and Michael A. Stroscio, Optical Phonon Modes in Rectangular Graphene Quantum Dots, Chinese Journal of Physics, 49 (1), 541-550 (2011).

Ayan Kar, Dimitri Alexson, Michael A. Stroscio, and Mitra Dutta, “Evidence of Compositional Inhomogenity in $In_xGa_{1-x}N$ alloys using Ultraviolet and Visible Raman Spectroscopy,” Journal of Applied Physics, 104, proof (2008).

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Jun Qian, Sicheng Liao, Song Xu, Michael A. Stroscio, and Mitra Dutta, Direct Measurement of Electical Transport through Single Molecules, Journal of Applied Physics, 106, 033702-1-8 (2009).

Mitra Dutta, Ke Sun, Yang Li, Vaishnavi Narayanamurthy, Kitt Reinhardt, and Michael A. Stroscio, Colloidal Quantum Dots (QDs) in Optoelectronic Devices --- Solar Cells, Photodetectors, Light-emitting Diodes, in Handbook for Self-Assembled Semiconductor Nanostructures for Novel Devices in Photonics and Electronics, edited by M. Henini, Elsever Publ. (Academic Press,2008); ISBN: 978-0-08-046325-4

Ke Sun, Milana Vasudev, Hye-Son Jung, Jianyong Yang, Ayan Kar, Yang Li, Kitt Reinhardt, Preston Snee, Michael A. Stroscio, and Mitra Dutta, Applications of Colloidal Quantum Dots, Microelectronics Journal, 40, 644-649 (2009).

Ke Sun, Michael A. Stroscio, Mitra Dutta, "Graphite C-axis Thermal Conductivity," Superlattices and Microstructures, 45(2), 60-64 (2009).

Ke Sun, Michael A. Stroscio, Mitra Dutta, "Thermal Conductivity of Carbon Nanotubes," Journal of Applied Physics, 105, 074316-1-5 (2009); also in Virtual Journal of Nanoscale Science and Technology, April 20, 2009; in February 2011 the Journal of Applied Physics stated that this paper was *one of the 20 top papers in terms of on-line downloads in a given month*.

PRESENTATIONS

Jun Qian , Mitra Dutta, and Michael A. Stroscio, Optical Phonon Modes in Rectangular Graphene Quantum Dots, Phonons 2010, Taipei, Taiwan, April 2010.

Sushmita Biswas, Mitra Dutta, Preston Snee, Michael A. Stroscio, Phonon modes in semiconductor quantum dots, Phonons 2010, Taipei, Tiawan, April 2010.

Jun Qian, Ke Sun, Mitra Dutta, Fellow IEEE, Michael A. Stroscio, Confined Phonons Effects, Phonon-carrier Interactions and Thermal Transport in Graphene-based Structures: Applications of Graphene, IEEE Nano, Korea, August 18, 2010. (Lead oral talk of session).

J. Qian, M. Dutta and M. A. Stroscio, Phonon Bottleneck Effects in Rectangular Graphene Quantum Dots, International Workshop on Computational Electronics (IWEC), Italy, October 2010.

S. Liao, M. Dutta, and M. Stroscio, Interface Optical Phonon Modes in Wurtzite Quantum Heterostructures International Workshop on Computational Electronics (IWEC), Italy, October 2010.

S. Liao, M. Dutta, and M. Stroscio, Multi-Color Photodetector based on Quantum Dots and Resonant-Tunneling Diodes Coupled with Conductive Polymers International Workshop on Computational Electronics (IWEC), Italy, October 2010.

Sushmita Biswas, Michael A. Stroscio, and Mitra Dutta, "Charge Transport in Nanocrystalline Quantum Dots and Composites with Polymers," Workshop on Quantum Dot Applications, University of Chicago, September 17, 2010.

Ayan Kar, Ke-Bin Low, Michael A. Stroscio, Mitra Dutta, Alan Nicholls, and M. Meyyappan, Investigation of Nucleation Mechanism and Tapering Observed in ZnO Nanowire Growth by Carbothermal Reduction Technique, Nanoscale Research Letters, in press (2010).

Sicheng Liao, Ke Sun, Mitra Dutta, and Michael A. Stroscio, Photodetector Based on GaN Double-Barrier Resonant Tunneling Diode Coupled with Colloidal Quantum Dots, abstract submitted to IEEE Nanotechnology Materials and Devices Conference (NMDC) will be held in Traverse City, Michigan, USA, June 2-5, 2009

Michael A. Stroscio, and Mitra Dutta, Sun Ke, Milana Vasudev, Jun Qian, Sicheng Liao, Takayuki Yamanaka, D. Ramadurai, Hye-Son Jung, Jianyong Yang, A. Rauchura, Yang Li, "Applications of Colloidal Quantum Dots and Carbon Nanostructures," University of Kentucky, September 24, 2008.

Sicheng Liao, Ke Sun, Michael Stroscio, Mitra Dutta, "Photodetector Based on GaN Double-Barrier Resonant Tunneling Diode Coupled with Colloidal Quantum Dots," 2009 IEEE Nanotechnology Materials and Devices Conference (NMDC 2009), June 2-5, 2009, Grand Traverse Resort and Spa, Traverse City, Michigan, USA; Proceedings of the 2009 Nanotechnology Materials and Devices Conference, IEEE Catalog Number CFP09NMD-CDR, ISBN 978-1-4244-4696-4, Library of Congress 2009904792 (2009)

Jun Qian, Sicheng Liao, Song Xu, Michael A. Stroscio, and Mitra Dutta, Electical Transport through Single Molecules by Distinct Tip-Surface Configurations, 2009 13th International Workshop on Computational Electronics, in Proceedings of the 2009 13th

International Workshop on Computational Electronics, pages 227-228, IEEE Catalog Number CFP09462-PRT, ISBN 978-1-4244-3926-3, Library of Congress No. 2009900737 (2009).

Jun Qian, Ke Sun, Mitra Dutta, Michael A. Stroscio, Confined Phonons Effects and Thermal Transport in Graphene-based Structures, MRS Symposium CC on Phonon Engineering for Enhanced Materials Solutions—Theory and Applications, MRS 2009 Fall Symposium (Invited)

(6) List of All Participating Scientific Personnel

Michael A. Stroscio, PI
Mitra Dutta, Co-PI
Jun Qian
Sicheng Liao
Xenia Meshik
Ayan Kar
Ke Xu
Nanzhu Zhang
Mohsen Purahmad
Shripriya Poduri

(7) Honors and Awards

The PI was:

Selected as Award Chairman for IEEE Nano in Seoul, Korea April 2010;

Reappointed to the Editorial Board of the IEEE Proceedings for a one-year term starting in January 2010;

Reappointed to a three-year term as a Member of the National Research Council (NRC) Board on Army Science and Technology (BAST);

Reappointed as an Executive Committee Member of the National Research Council (NRC) Board on Army Science and Technology (BAST)

Appointed as a Member of the US Air Force Scientific Advisory Board AF SAB

Reappointed as the Richard and Loan Hill Professor

(8) Report of Inventions: None